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ABSTRACT

Recent advances in information technology have made feasible the development of intelligent computer assisted instruction study units. Analysis and design of such systems require the active involvement of a development team consisting of domain experts, educators, and knowledge engineers. Science and technology teaching methods are frequently domain-independent. The important component that changes is the domain knowledge. This is the basis for the analysis and development of an intelligent computer assisted instruction (ICAI) shell. An object-process analysis approach is applied to analyze the shell, the users, the system's modules, and the relationships among them. The object-process diagram is used as a tool to visualize the relationships between objects and processes in the ICAI shell. To exemplify some of the concepts, a case study of a courseware development process of a CAI polymer unit is provided. Four figures illustrate object-process analysis. (Author)

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Object-Process Analysis of Intelligent Computer Assisted Instruction Shell: the Polymer Courseware - a Case in Point

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Abstract: Recent advances in information technology have made feasible the development of intelligent computer assisted instruction study units. Analysis and design of such systems require the active involvement of a development team consisting of domain experts, educators and knowledge engineers. Science and technology teaching methodologies are frequently domain-independent. The important component that changes is the domain knowledge. This is the basis for the analysis and development of an Intelligent Computer Assisted Instruction (ICAI) shell. We apply an object-process analysis analysis approach to analyze the shell, the users, the system's modules and the relationships among them. The object-process diagram is used as a tool to visualize the relationships between objects and processes in the ICAI Shell. To exemplify some of the concepts, we provide a case study of a courseware development process of a CAI Polymer unit.

Theoretical foundations of the teaching/learning process on one hand and recent advances in multimedia technology on the other hand, have made possible the creation of a learning environment that benefits from both. Science and technology teaching methodologies are frequently domain-independent. The important component that changes is the domain knowledge. This is the basis for the analysis of a shell for Intelligent Computer Assisted Instruction (ICAI) development. The division of the learning environment and science or technology domain of study, into two distinct components of a studyware opens the way for the development of a generic framework that supports studyware authoring (Dori, Dori and Yochim, 1992). Such a framework, or "shell," should enable the expert team, charged with the curriculum development, to concentrate on a sound presentation and teaching of the subject matter. At the same time, the shell is supposed to take care of putting the subject matter in the right educational context, relieving the developers from the burden of low level programming such as graphic user interface and repetitive tasks. The approach of a shell architecture is coherent with the reusability principle of software engineering: rather than "reinventing the wheel," software development should capitalize on existing code modules that have been extensively tested and proven to be reliable and efficient. Applied to our objective, on top of all this, education principles embedded in the shell would ensure a good starting point for ICAI developers.

An ICAI shell is a very large development project. A project of this order of magnitude requires a well founded methodology of systems analysis, design and implementation. This work uses an object-process analysis (OPA) approach (Dori, Phillips and Haralick, 1994) to visualize and analyze the shell, the users, the system's modules and the relationships among them. The OPA approach combines the object-oriented analysis (OOA) approach (Jacobson et al., 1992; Shlaer and Mellor, 1992), to represent the static-structural aspects, and the Data Flow Diagram (DFD) proposed by De Marco, (1978) and Yourdon and Constantine, (1978) to represent the dynamic-procedural aspects, into one integrated representation approach. The basic observation underlying the object process approach is that every thing can be classified as an object or as a process.

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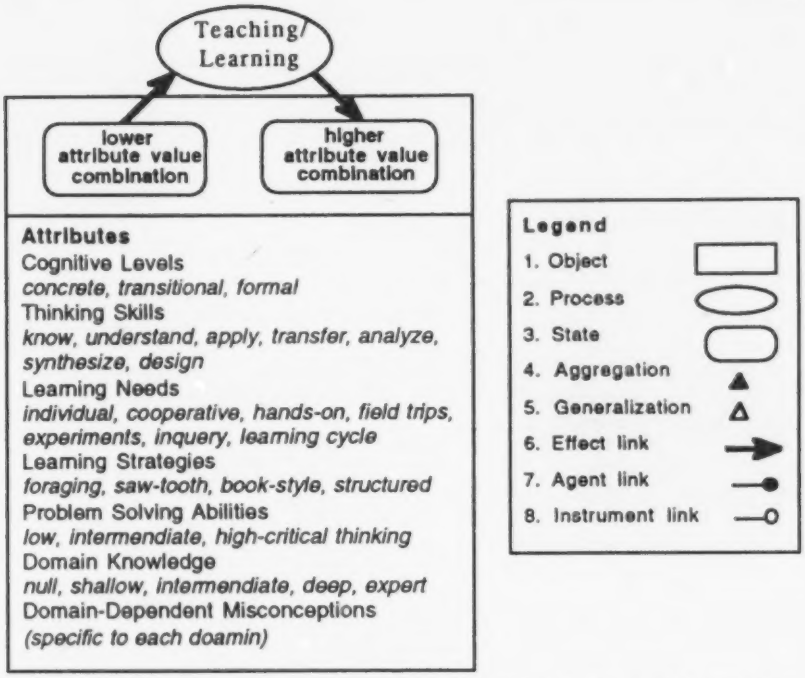

Figure 1. *An OPD showing the student's attributes and their possible values*

An Object-Process Diagram (OPD) is a diagram that depicts the classes within the system and the structural and procedural relations among them. The OPD uses a number of symbols, shown in the legend of Figure 1. One is the effect link, which leads from objects to processes and vice versa, describing the input and output objects needed to maintain the process. Another pair of symbols are blank and solid disks terminating a line, which denote instrument and agent links, respectively. An instrument link connects the object which is needed to carry out the process at which it points. The agent link connects the object (usually person), which carries out the process at which it points. Finally, the solid and blank triangles denote the two basic structural relations whole-part and generalization-specialization, respectively. The whole-part relation denotes aggregation of one or more classes to a higher-level class. The generalization-specialization (gen-spec, or "is-a" relation) denotes the specialization of a higher-level class.

The Student and the Teaching/Learning Process

The end user – the student – is modeled as an object affected by the teaching/learning process. Each student can be characterized by a set of attributes which, at a given point in time have a particular combination of attribute values. The major student's attributes which are of interest for an educator are listed in Figure 1. The possible values for each such attribute are listed beside each attribute. Where applicable, they are arranged in an increasing order of advancement and/or sophistication. A student may, for example, have a concrete Cognitive Level, with Thinking Skill *understand*, with *individual* and *hands-on* Learning Needs, with book-style Learning Strategy, low Problem Solving ability, shallow Domain Knowledge, and Domain-Specific Misconceptions X and Z. This attribute value combination is one state in the state space. The state space is the collection of all the possible attribute value combinations a student may assume. The purpose of the Teaching/Learning process is to transfer a student from a state with a given attribute value combination to another state, in which the overall attribute value combination is higher. The most common improvement is expected to occur in the value of the Domain-Specific Knowledge, but, at least in the long run, Teaching/Learning process is expected to yield improvements in attributes such as Thinking Skills, Problem Solving Abilities and Learning

Strategies. Figure 1 is an Object-Process Diagram (OPD), in which Student is the object, represented as a rectangle with a state-transition diagram at its upper compartment, consisting of two states, represented as rounded-corner rectangles, and with the list of attributes and their possible values at the lower compartment. The Teaching/Learning process, depicted as a bubble (ellipse), is shown changing the student's state from lower to higher attribute value combination. With the above definition of the student's states the Teaching/Learning process, we proceed to describe an overall concept of the ICAI Shell. it consists of the Student Module, the Expertise Module, and the Teaching/Learning Module.

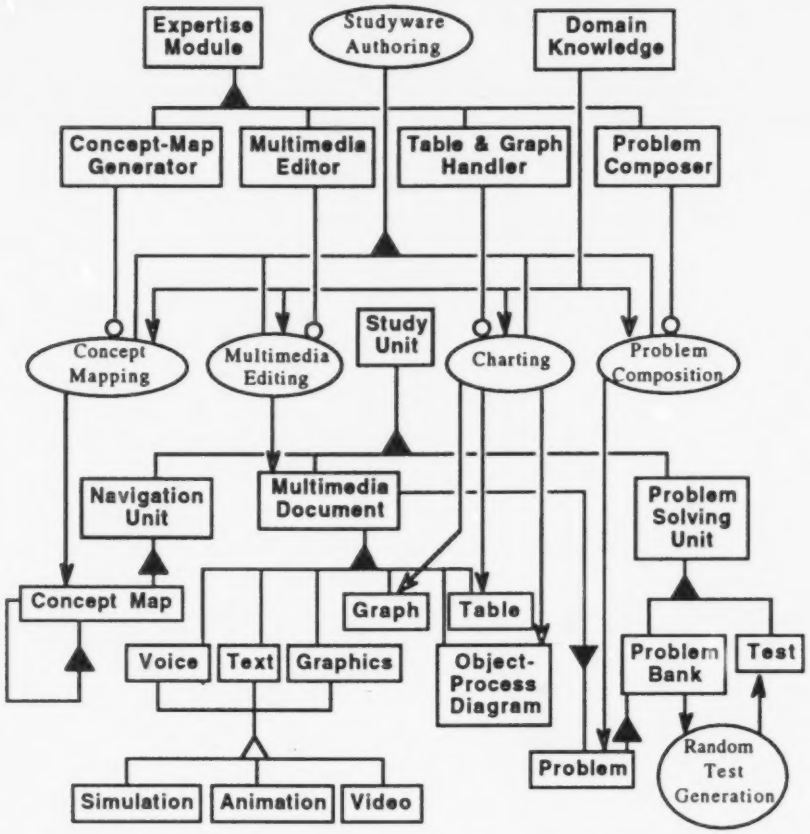

Figure 2. *An OPD of the studyware authoring process and the resulting study unit*

The Expertise Module Object within the ICAI Shell

The Expertise Module object class and the Studyware Authoring process class are shown in Figure 2. The Expertise Module consists of four objects: the Concept-Map Generator, the Multimedia Editor, the Table&Graph Handler, and the Problem Composer. The Concept-Map Generator is a tool for the process of Concept Mapping – a powerful means for the representation of knowledge at various levels of depth. It enables easy and reliable construction of concept maps that are linked to each other as described by Fisher (1990). Computerized concepts maps may enable navigation around the study unit and, possibly, to and from other study units. It also helps students in putting concepts in the right context, thereby organizing pieces of knowledge in a meaningful way. An advanced option of this generator can be its ability to draw Object Process Diagrams, such as the figures in this work. Thus, concept maps in the ICAI Shell environment use the notation and semantics of the object-process paradigm, yielding an enhanced version of concept maps. The Table&Graph Handler is an electronic spreadsheets that enables making tables and graphs

and define constraints among table cells. It is used for Charting and produces Graphs and Tables. One example, described by Linn and Songer (1991), makes use of a similar tool for teaching thermodynamics for middle school students to help them construct more abstract and general scientific principles at a macroscopic level.

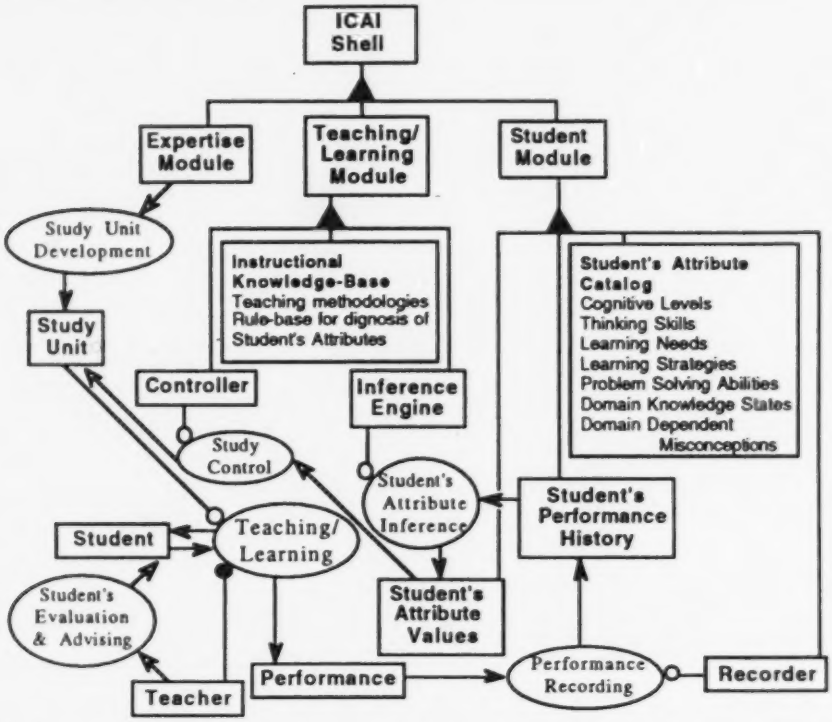

Figure 3. *The interaction between Student, Teacher, Study Unit and the ICAI Shell*

The Problem Composer is the fourth component of the Expertise Module. It has a variety of problem templates for various kinds of problems, such as push-button multiple choice combinations. It is used in the process of Problem Composition which results in Problems for the Problem Bank (Dori and Yochim, 1990). Each problem is characterized by the topics it is designed to test, the template used and the degree of difficulty. The Studyware Authoring process then consists of Concept Mapping, Multimedia Editing, Charting, and Problem Composition. The result of these processes is the Study Unit, which, in turn, consists of a Navigation Unit, a Multimedia Document, and a Problem Solving Unit. The Navigation Unit is responsible for orientation of the student in the web of screens so that he or she does not get lost and can always find out "where am I".

The Multimedia Editor is a composite software component for multimedia document authoring. The Problem Solving Unit consists of a Problem Bank and Tests which are generated by randomly selecting problems with the appropriate attributes. Tests and quizzes are characterized as being either voluntary or mandatory. This mechanism ensures that the student does not browse aimlessly throughout the entire module and across modules before obtaining a minimal level of knowledge about the subject matter he has studied (Yochim and Dori, 1993). The Expertise module is one of the three modules of the ICAI Shell, the other two being the Teaching/Learning Module and the Student Module (see Figure 3). The Student Module contains a Student Attribute Catalog with the attributes and values, described in Figure 1. For each individual student, this module keeps record of Performance History and Attribute Values. The Recorder monitors and records students' responses of interest, such as the order and duration of viewing cards, answers to quizzes and tests, etc. The Teaching/Learning Module is the heart of the ICAI Shell. It has an Instructional Knowledge Base with Teaching Methodologies and a Rule-Base for diagnosis of students'

attributes. It has a Controller and an Inference Engine that, based on the Student's Performance History and current Performance, infers and updates the current Student's Attribute values. These are used for the process of Study Control which is done by the Controller. It controls the learning pace, depth and abstraction level. The Student is engaged in the process of Teaching/Learning in which the Study Unit is the instrument and the human Teacher is the agent. Using data from the Student Module regarding present and past performance, the teacher also evaluates the student and advises for effective learning strategies.

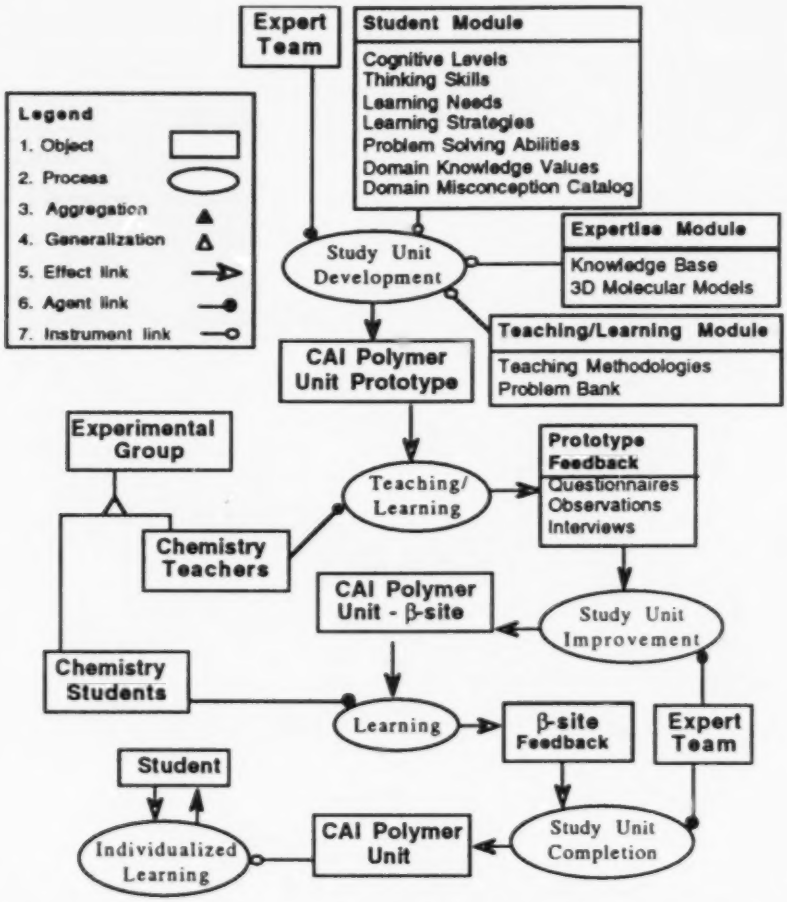

Figure 4. *An Object-Process Diagram of the Polymer Courseware Authoring*

The Polymer Courseware Authoring: a Case in Point

To exemplify some of the concepts introduced in the previous sections, we provide an example of a complete courseware development process of a Computer Aided Instruction Polymer unit (Dori and Barnea, 1993). Figure 4 is an OPD of the CAI Polymer Unit development. The agent that authors the courseware is the expert team, which includes experts in the area of the chemistry of polymers and science education. The products (objects) of this process are the Student, Expertise, and Teaching/Learning Modules. As a preliminary activity, the expert team analyzed the Students' Attributes and Teaching Methodologies relevant to the particular subject matter - the study of polymers. For example, a major learning need has been found to be understanding the properties of macromolecules that are related to their three-dimensional structure. Accordingly, one teaching methodology

was set to be 3D Molecular Modeling. The outcome of the Study Unit Development Process was the CAI Polymer Unit Prototype. The Prototype was used by an Experiment Group of Chemistry Teachers who took part in an in-service training aimed at both introducing the teachers to the Unit and obtaining feedback on the prototype. The Prototype Feedback, which was compiled from a series of (pre- and post-training) Questionnaires, Observations and Interviews, was used by the Expert Team for the process of Study Unit Improvement, which resulted the β-site CAI Polymer Unit version.

Students who major in chemistry were the Experiment Group for the β-site version, and the β-site Feedback obtained form them was the input to the Study Unit Completion. The end product – the CAI Polymer Unit – is the object used as an instrument for the Individualized Learning process by the Student. This process potentially changes the student's attribute values from a lower to a higher combination.

Summary

We have presented an Object-Process analysis of a system for developing courseware. With the resulting study units, students can engage in active learning while the system monitors their responses and reacts accordingly, imitating the role of an exemplary teacher. This Object-Process analysis serves as an architecture for an Intelligent Computer Assisted Instruction Shell. It is based on a holistic view of the student as an object and the teaching/learning as a process that transforms him/her from a state of lower attribute value combination to a higher one. A key factor in this system is the enabling technology of multimedia, which opens the way for the creation of a multi-faceted learning environment and suits the non-linear nature of knowledge, which is so difficult to convey by books. A preliminary stage in the development of these concepts has been presented as a case in point by the CAI Polymer Unit Development Process. We believe that the concepts and architecture proposed here will be eventually materialized and take advantage of the synergy between the opportunities offered by modern educational theories and technological advances.

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